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# Spin dynamics of excitons in GaAs/AlGaAs superlattices in a magnetic field

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**Abstract.** Kinetics of resonance luminescence of GaAs/AlGaAs-superlattices in circular and linear polarizations is studied in a magnetic field of up to 5 T. Quantum beats of the luminescence are detected and their nature is identified. The energy and phase relaxation rates of excitonic spins are determined from the experimental data.

The spin relaxation times of electrons and holes in the GaAs-based high-quality heterostructures may amount to as much as hundreds of picosecond or even units of nanosecond [1–3]. At the same time, the spin relaxation rate of electron-hole pairs (excitons) couples by the Coulomb interaction appear to be essentially higher. Even under favorable conditions (low temperatures and low excitation power densities), the appropriate relaxation times do not exceed several tens of picoseconds. In the literature, several relaxation channels were discussed: independent electron or hole spin flips [4], relaxation of the electron magnetic moment as a whole [5], and reversible dephasing associated with inhomogeneous broadening of the excitonic fine structure [6]. Still, the predominant mechanism of the excitonic spin relaxation remains so far obscure.

In this note, we present results of experiments on dynamics of polarized resonance luminescence of HH-excitons in the GaAs/AlGaAs superlattices. The measurements were made both in linear and circular polarizations in an external magnetic field parallel to the structure growth axis. A joint analysis of the data thus obtained has allowed us to identify mechanisms of the energy and phase relaxation of magnetic moments and to evaluate role of each of them in dynamics of the polarized luminescence.

## 1. Experimental data

We studied a heterostructure with 50 periods of the superlattice with the GaAs and $Ga_{0.56}Al_{0.44}As$ layers 30 and 38 Å thick, respectively. The exciton linewidth in the steady-state luminescence spectrum at 4.2 K was 6 meV, with the Stokes shift between maxima of the luminescence and absorption lines being around 5 meV. The luminescence was excited by a tunable Ti-sapphire laser with the pulsewidth $3 \div 5$ ps. The luminescence kinetics was detected in real time using a Sinchroscan streak-camera. Spectral and time resolution of the detection system was 0.5 meV and 5 ps, respectively. The measurements were performed in conditions when spectra and kinetics of the photoluminescence did not depend on the pump power density. The magnetic field up to 5 T was produced by a superconducting solenoid immersed in liquid helium.

The luminescence was excited near the peak of the exciton absorption line. The luminescence was detected at the wavelength slightly shifted (by around 2 meV) toward long

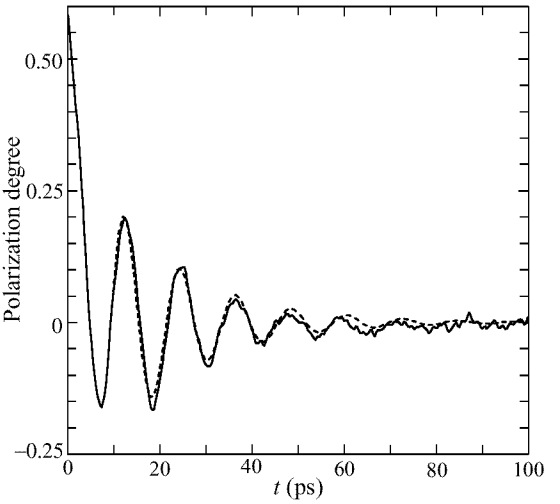


**Fig. 1.** The dynamics of linear polarization degree in longitudinal magnetic field $B = 5$ T. Full curve is experiment; dashed curve is theoretical fit.

wavelengths with respect to the excitation wavelength. Such a detuning, as has been established previously [7], does not noticeably change the luminescence polarization degree and, at the same time, allows one to completely eliminate the stray laser light.

The experiments have shown that, in the magnetic field parallel to the structure growth axis $z$ (longitudinal field), the luminescence pulses detected in two orthogonal linear polarizations show well pronounced oscillations. Figure 1 shows dynamics of the degree of polarization measured in these conditions. Degree of polarization was defined in a conventional way by the formulae $p = (I_1 - I_2)/(I_1 + I_2)$, where $I_1$ and $I_2$ are the PL intensities in two orthogonal polarizations. The degree of polarization is seen to oscillate symmetrically with respect to horizontal axis, with the oscillation amplitude decaying in time. Fitting the

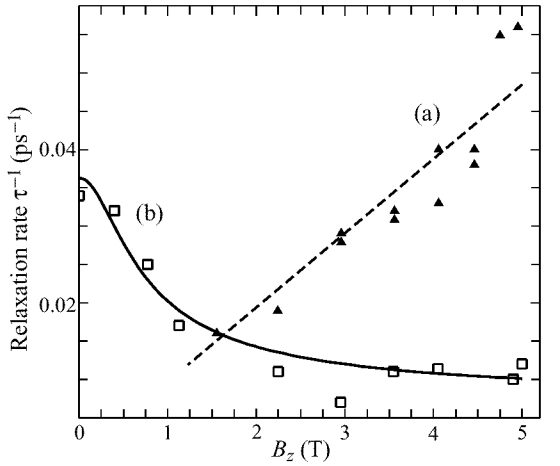


**Fig. 2.** Field dependence of relaxation rates: (a) the rate of oscillations damping in linear polarization; (b) the rate of circular polarization degree decay. Points—experimental data; curves is the guide for eye.

experimental curve by the function: $p(t) = p_0 \exp(-t/\tau_\pi \times \cos(\omega_\pi t + \varphi)$ allowed us to determine, from the experimental data, the oscillation frequency $\omega_\pi$ and the decay time $\tau_\pi$. The measurements made at different values of the magnetic field strength $B$ have shown that the oscillation frequency $\omega_\pi$ in magnetic fields up to 5 T is a linear function of $B$. It has been found also that the decay rate $\tau_\pi^{-1}$ increases with the field strength (curve $a$ in Fig. 2).

Dynamics of the circularly polarized luminescence in longitudinal magnetic field appears to be essentially different. The degree of circular polarization $p_\sigma$ does not show oscillations and decays monotonically in time. A considerable portion of the decay curve $p_\sigma$(t) can be approximated by an exponential function with the decay time $\tau_\sigma$. It is important that the relaxation rate of the degree of circular polarization $\tau_\sigma^{-1}$ in the field $B = 5$ T appears to be smaller by a factor of 5 than the relaxation rate of the beats in linear polarization $\tau_\pi^{-1}$. Moreover, as seen from Fig. 2, these quantities depend differently on the magnetic field strength.

## 2. Analysis of the results

The oscillations detected experimentally are related to quantum beats between Zeeman sublevels of the excitonic fine structure. As is known [8], the HH-exciton states in the GaAs-based structures are four-fold degenerate in total angular momentum. Exchange interaction between the electron and hole splits this quartet into two doublets – optically active ($J_z = 1$) and optically inactive ($J_z = 2$). The magnetic field, directed along the growth axis, splits the optically active doublet into the components $J_z = +1$ and $J_z = -1$, with transitions to these component corresponding to the right- and left-hand oscillators. Circularly polarized light excites only one component, and observation of the luminescence in orthogonal polarization becomes possible only after energy relaxation of the excitonic angular moment, characterized by the time constant $T_1$. It is this time that determines the decay rate of the degree of circular polarization of the luminescence, i.e., $\tau_\sigma^{-1} = T_1^{-1}$. The linearly polarized excitation creates coherent superposition of the states $J_z = +1$ and $J_z = -1$, which gives rise to beats in the degree of linear polarization of the emission (Fig. 1). The oscillation frequency is determined by the magnitude of the splitting, while the decay of the beats is related to decay of the coherence. The decay constant, in this case, is given by the relationship [4]: $\tau_\pi^{-1} = (2T_1)^{-1} + T_2^{-1}$, where $T_2$ is the dephasing time of the excitonic fine structure states. Comparison of the quantities $\tau_\sigma^{-1}$ and $\tau_\pi^{-1}$ makes it possible to determine independently the values of the energy and phase relaxation rates in the system under study. As is seen from Fig. 2 (curve $b$), the relaxation rate of the circular polarization in the fields above $B = 1$ T practically does not depend on the field strength and makes up $1 \times 10^{10}$ s$^{-1}$. It is this value that should be ascribed to the energy relaxation rate between sublevels of the optically active excitonic state, split by the magnetic field. Behavior of the coherence decay rates (curve $a$ in Fig. 2) appears to be essentially different, i. e. the quantity $\tau_\pi^{-1}$ increases with the field, reaching $5.4 \times 10^{10}$ s$^{-1}$ at $B = 5$ T. It follows from the difference between behavior of the quantities $\tau_\pi^{-1}$ and $\tau_\sigma^{-1}$ that the main reason for decay of the beats in linear polarization is the phase (rather than the energy) relaxation, characterized by the time $T_2$. The linear dependence of $\tau_\pi^{-1}$ on the field strength indicates that decay of the beats is associated with inhomogeneous spread of the excitonic $g$-factor, giving rise to corresponding spread of the splittings and, as a result, to spreading the phases of elementary emitters (the so-called reversible phase relaxation [9]).

A significant increase of $\tau_\sigma^{-1}$ in the fields below $B = 1$ T is likely to be caused by local anisotropy of the structures under study in the planes of heterolayers. This anisotropy arises

due to inhomogeneities in interfaces [3] and, for this reason, the value of the splitting and orientation of the oscillators in the layer plane can be random. In this case, any polarized excitation will create a coherent superposition of the split states, which will decay due to the reversible phase relaxation related to variations of the splitting. It is believed that this process is responsible for depolarization of the luminescence in the absence of magnetic field. The external magnetic field, parallel to the growth axis, suppresses the splitting caused by the in-plane anisotropy. This eliminates conditions needed for the reversible phase relaxation and, as a result, the quantity $\tau_\sigma^{-1}$ decreases.

## 3. Conclusion

In summary, the studies of kinetics of resonance photoluminescence of the GaAs/AlGaAs superlattice in external magnetic field has allowed us to obtain fundamentally new information about intrinsic dynamics of the exciton angular moment. We have determined separately the energy and phase relaxation rates between components of the optically active doublet. The energy relaxation rate is established to be independent of the external magnetic field strength within the range $1 \div 5$ T. It is concluded, from dependence of the phase relaxation rate on the magnetic field strength, that the relaxation is reversible and is therefore related to inhomogeneous spread of the excitonic $g$-factor. It is suggested that the main reason for depolarization of the resonance excitonic luminescence, in the absence of magnetic field, is also the reversible phase relaxation of excitonic fine structure states. Mechanism of the relaxation is related to statistical spread of local splittings of the optically active doublet, caused by inhomogeneous strains in the plane of the heterostructure.

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